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Enhancing Disaster Resilience Through Risk Assessment and Sustainable Planning in The Lekki-Epe Corridor, Lagos

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Abstract

The resilience of coastal areas is seriously threatened by environmental degradation, urbanisation, and climate change. The study examines the vulnerability of the Lekki-Epe corridor in Lagos State, Nigeria, to flooding, with an emphasis on ecological risk and socio-economic impact, among other factors. Using geospatial analysis, Ordinary Weighted Average (OWA) and Multi-criteria Decision Analysis (MCDA), integrated vulnerability mapping was conducted to assess susceptibility levels across different areas. The results indicate that a substantial portion (69.3%) of the study area falls within the very vulnerable category, particularly in rapidly urbanising zones where wetland encroachment and poor drainage infrastructure exacerbate environmental hazards. The study emphasises how these vulnerabilities have social and economic repercussions, such as greater susceptibility to climate-induced floods, community displacement, infrastructure destruction, and economic disruptions. To enhance resilience, the results highlight the necessity of better land-use regulations, coordinated urban planning, and the utilisation of nature-based solutions. Additionally, there is a need for stronger environmental governance, building of flood-resistant infrastructure, and the use of geospatial technology for early warning and real-time monitoring of catastrophes. Future research should explore dynamic climate modelling, real-time vulnerability assessments, and participatory planning approaches to improve disaster risk reduction strategies. This study contributes to the growing discourse on urban disaster resilience, providing insights for policymakers, urban planners, and environmental scientists seeking to mitigate vulnerabilities in rapidly developing coastal regions.

1. Introduction

Coastal cities are particularly vulnerable to hazards due to their low elevation and proximity to the ocean [1], [2]. A complex network of hazards, resulting from ill-planned growth, climate change, and environmental degradation, exacerbates vulnerability, especially in rapidly growing coastal cities. Urgent and robust intervention is required to enhance urban disaster resilience, safeguarding infrastructure, economic activity, and human life. Urban disaster resilience in this sense refers to the ability of urban systems to endure, adapt, and recover from disasters while maintaining critical operations [2], [3]. Improving urban disaster resilience requires effective risk assessment and sustainable planning, particularly in coastal areas where dynamic interactions between human and natural systems increase vulnerabilities.

While environmental hazard studies often use the concepts of vulnerability, risk, and resilience interchangeably, they represent distinct yet interconnected dimensions of disaster management. Vulnerability refers to the susceptibility of a system, population, or environment to harm due to exposure, sensitivity, and limited adaptive capacity; the Intergovernmental Panel on Climate Change (IPCC) defines it as the "propensity or predisposition to be adversely affected" [4]. In contrast, risk refers to the potential for losses or adverse impacts resulting from the interaction of hazards, exposure, and vulnerability. According to the United Nations Office for Disaster Risk Reduction (UNDRR), disaster risk is the potential loss of lives, livelihoods, infrastructure, and environmental assets caused by hazardous events over a given period [5]. For instance, flood risk in the Lekki-Epe corridor increases when intense rainfall, sea level rise, and poor drainage systems affect highly exposed communities. Resilience, however, refers to the capacity of a system, community, or ecosystem to resist, absorb, adapt to, and recover from hazards while maintaining essential functions [4], [5]. Therefore, vulnerability explains susceptibility to harm, risk reflects the probability and magnitude of loss, while resilience emphasizes the ability to recover and adapt after hazardous events.

Geographic information systems (GIS) and remote sensing (RS) have become effective tools for addressing these issues, offering several benefits over conventional urban planning and risk assessment approaches. Specifically, while RS offer thorough, high-resolution, and real-time spatial data, in contrast to traditional methods that depend on field surveys and manual data collection [6], GIS offer diverse databases (including elevation, vegetation density, rainfall, land use/cover, and population distribution), and integration capabilities which facilitates a more holistic understanding of disaster risks and resilience factors in urban areas. Additionally, RS and GIS provide sophisticated analytical methods such as spatial modelling and Multi-Criteria Decision Analysis (MCDA), which are critical for allocating resources optimally and prioritising interventions [7].

Although several studies have examined flooding, coastal erosion, and urban expansion in Lagos [8][9]. limited research has specifically provided an integrated assessment of flood vulnerability in the Lekki–Epe corridor that simultaneously combines geospatial vulnerability mapping and ecological risk analysis. Most existing studies tend to focus on either physical flood occurrences, shoreline changes, or urban growth independently, with insufficient attention given to how rapid urbanisation, wetland degradation, and climate change collectively interact to increase vulnerability in this rapidly developing coastal corridor. This study addresses these gaps by providing a spatially explicit and multidisciplinary vulnerability assessment to support sustainable coastal planning and disaster risk reduction.

This study evaluates the vulnerabilities, identify high-risk areas, and suggest sustainable planning techniques that improve urban disaster resilience in Lekki-Epe corridor by utilising RS and GIS. The application of RS and GIS is especially pertinent due to the region's complex geography, industrial and socioeconomic importance, and environmental sensitivity. Natural ecosystems, residential areas, and vital infrastructure are all located along the corridor, and they are increasingly threatened by man-made and natural hazards. Risk assessments in this area can make significant contribution to disaster risk management in Lagos State since it is not only germane but also essential for the Lekki-Epe corridor's sustainable development.

The study advances our understanding of sustainable urban development by highlighting the value of RS, GIS, and MCDA in urban resilience planning. The techniques and knowledge gained can serve as a guide for other coastal cities facing similar challenges. This study also supports global efforts to enhance urban resilience, as outlined in the UN Sustainable Development Goals (SDGs), specifically SDG 11 on Sustainable Cities and Communities. Knowledge gathered from this research will support sustainable urban development, inform evidence-based decision-making, and enhance Lagos State's capacity to withstand future calamities.

To assess the vulnerability of the Lekki–Epe corridor in Lagos State, Nigeria, considering the effects of environmental degradation, rapid urbanisation, and climate change, this study analysed the spatial distribution of flood vulnerability in the Lekki–Epe corridor using geospatial techniques and propose appropriate resilience and mitigation strategies, including improved land-use planning, nature-based solutions, and early warning systems.

2. Materials and Methods

2.1 Study Area

The Lekki-Epe corridor is a rapidly developing coastal region located in the southeastern part of Lagos State, Nigeria. It extends from the bustling urban centre of Lekki in the Eti-Osa Local Government Area (LGA) to the more rural and emerging areas of Ibeju-Lekki and Epe LGAs. This coastal stretch is approximately 70 kilometres long. It is one of the most dynamic and vulnerable areas of the state, bordered to the north by the Lagos Lagoon and to the south by the Atlantic Ocean (Figure 1). In recent years, the Lekki-Epe corridor has experienced a tremendous increase in population and infrastructure development, driven by government and private sector investments [10]. The Lekki Free Trade Zone, the Dangote Refinery, the Lekki Deep Sea Port, and several upscale housing projects are among the region's most significant developments [11]. Additionally, the area is home to significant natural habitats, including wetlands and mangrove forests, which provide vital ecosystem services, such as water management and storm protection [8].

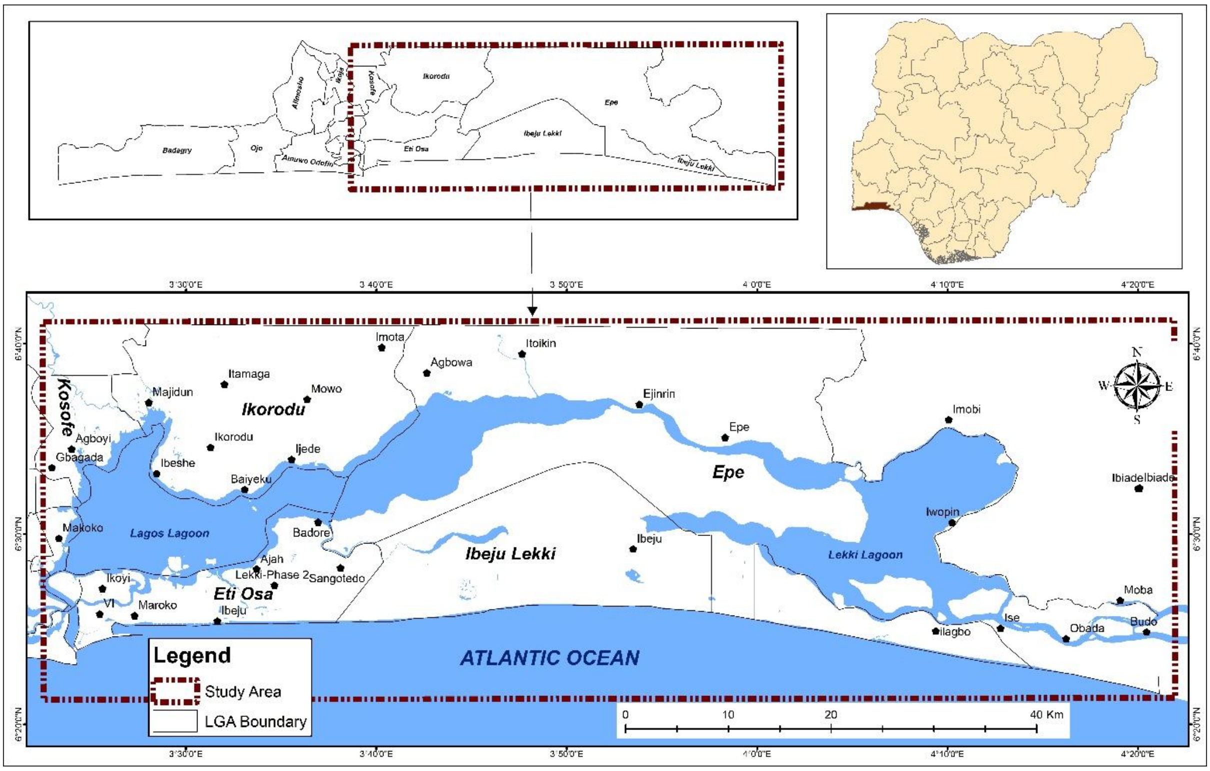

Fig. 1 *Lekki-Epe corridor*

With distinct rainy and dry seasons, the corridor has a tropical wet and dry climate [12], [13]. Heavy rainfall, especially during the rainy season (April to October), puts the area at risk of flooding. The Atlantic coastline is susceptible to erosion due to rising sea levels and increased wave action, which endanger both human settlements and natural habitats. The presence of sandbars, barrier islands, and tidal flats along the coastline further complicates the region's hydrological dynamics. The rapid urbanisation in the Lekki-Epe corridor has turned the hitherto underdeveloped coastal area into a vital economic hub [14]. As a result of urbanisation, natural areas such as forest and wetlands have been transformed into residential, commercial, and industrial projects [15].

Due to this change, the area is now more vulnerable to environmental risks, including habitat deterioration, erosion, and coastal flooding. With its affluent estates, financial institutions, and tourism amenities, Eti-Osa LGA's Lekki Peninsula has developed into a significant residential and business centre. As one moves east, Ibeju-Lekki is becoming a centre of industry and commerce, due to significant infrastructure projects such as the Lekki Deep Sea Port, the Dangote Refinery, and the Lekki Free Trade Zone. Meanwhile, Epe LGA retains much of its rural character but is gradually urbanising as Lagos expands outward.

The Lekki-Epe corridor is a vital area for Lagos State's economic development. However, it faces significant environmental and infrastructural challenges. As development continues at a rapid pace, the need for sustainable urban planning that is hinged on disaster risk management becomes increasingly important. This study area, with its unique blend of urban, industrial, and natural landscapes, serves as a critical zone for understanding the on-going interactions between human activities, environmental change, and disaster resilience.

2.2 Data Type and Source

Several datasets were used in this study, sourced from both satellite imagery and secondary data sources, as presented in Table 1. The population for the study area, for example, was sourced from Meta raster population data. The Normalized Difference Vegetative Index (NDVI), Normalized Difference Water Index (NDWI) and proximate data for the study were derivatives and extractions from analyzed Landsat 8 satellite image. Finally, the rainfall and elevation data were sourced from the National Aeronautics and Space Administration and Google Earth resources respectively as described in Table 1.

Table 1 *Data source description*

Data Type	Source	Duration	Scale/ Resolution	Purpose	Detail of Data Extraction
Elevation	Google Earth Resources https://www.google.com/maps/@6.5136621,3.3892904,4699m/data=!3m1!1e3!5m1!1e4?entry=ttu	2022	11,920 data points	To identify low-lying areas prone to flooding & assess elevation-related vulnerabilities	Weighted using the Inverse Distance Weighted (IDW) & clipped to study area
Population	Meta (https://data.humdata.org/organization/facebook?q=high%20resolution%20population%20density&ext_page_size=100),	2020		To analyse human exposure and vulnerability to flooding based on population density	Computed and summarised to ward levels and presented in charts, tables and maps.
NDVI	USGS's Global visualisation viewer http://glovis.usgs.gov/index.shtml	2022	Spatial Resolution: 15 (P), 30m (B- IR), 30m (C), 100m (TIR); Spectral Resolution: 11bands (0.43-2.29µm, 10.6-12.5µm	As a proxy for Vegetation: to assess vegetation cover's role in reducing surface runoff and enhancing flood resilience	Extraction from analysed Landsat 8 map (2022) and clipped to the study area extent.
NDWI				As a proxy for the presence of water: to assess proximity to waterbodies and their role in flood risk assessment and management	
Proximity to water & wetland					Extracted from LU/LC (2022): clipped to the study area, vectorised, extracting water and wetland and weighted using the Euclidean distance approach
Rainfall intensity (mm)	The National Aeronautics and Space Administration's POWER database (https://power.larc.nasa.gov/)	2013-2022	25 data points; 0.5 x 0.625-degree resolution	To evaluate rainfall patterns and their impact on flood risk	Decadal average & Weighted using the Inverse IDW & clipped to the study area

Meta (Facebook) high-resolution population density data were used because they provide 30 m spatial estimates suitable for rapidly urbanizing areas like the Lekki–Epe corridor, where census data may be outdated or aggregated. The dataset integrates satellite imagery, machine learning-based building detection, and census inputs, with a reported validation accuracy of 0.95 precision and 0.91 recall, supporting its reliability for spatial planning and disaster-risk analysis [16]. Although widely used by organisations such as the World Bank for planning in data-scarce regions, limitations include the possible under-representation of informal settlements and privacy-related masking, which were mitigated through cross-validation with land-use maps, field data, and demographic records.

2.3 Data Processing and Analysis

2.3.1 Multi-Criteria Decision Analysis (MCDA) Using Ordinary Weighted Average (OWA)

A multi-criteria decision analysis (MCDA) framework was adopted to assess the overall flood resilience using the Ordinary Weighted Average (OWA) method. The Multi-Criteria Decision Analysis (MCDA) is a decision-support framework used to evaluate and rank alternatives based on multiple environmental, social, technical, and economic criteria. In environmental planning, MCDA helps identify the most suitable option where competing interests and complex trade-offs exist. The OWA technique on its part allows for the combination of multiple criteria by assigning weights to each factor, reflecting their relative importance in determining flood resilience. The OWA method, along with different drivers and sets of ordered weights, was adopted as they are known to apply to a wide range of multi-criteria evaluation strategies [17], and to provide decision-makers with a quantitative assessment of a range of scenarios, from very optimistic to pessimistic [18]. Thus, a variety of risk attributes among decision-makers was assessed as a factor known to influencing the result [19].

The drivers or criteria were ranked based on the uncertainty resulting from their interaction [20]. The set of weights controls the relative contribution of a specific criterion. The advantage of the OWA method is that the decision-maker can produce a wide range of maps and different solutions and scenarios by rearranging and changing criteria [21]. The OWA analysis inculcates a wide range of risk scenarios prepared within the Eti-Osa LGA of Lagos state and expressed using the following equation:

$$OWA = \sum_{j-1}^{n} \left(\frac{w_j v_j}{\sum_{j=1}^{n} w_j v_j} \right) Z_{ij} \tag{1}$$

Where *vj* is the order weight, *wj* is the criterion weight, and *Zij* is the attribute value of the *j* criterion of the *i* pixel that has been standardised and hierarchically assigned [22].

The steps involved in the OWA analysis are as follows:

Criteria Selection and Standardization: The key factors identified (elevation, rainfall, vegetation density, presence of water, proximity to waterbody and wetland resources, population, building footprint, and transport facilities) were standardised on a common scale, allowing for meaningful comparisons.

Weight Assignment: Based on expert judgment and literature, weights were assigned to each criterion. For instance, elevation and rainfall were given higher weights due to their direct influence on flood susceptibility. In contrast, population and building footprint were weighted to reflect the vulnerability of human settlements.

Aggregation: Using the OWA algorithm, the criteria were aggregated to produce a composite flood resilience index. This index provides a spatial representation of areas that are more or less resilient to flooding.

Sensitivity Analysis: To validate the robustness of the OWA results, a sensitivity analysis was performed by adjusting the weights of different criteria. This ensures that the final flood resilience map is not overly dependent on subjective weight choices.

Mapping and Visualisation: The results from the OWA analysis were visualised through GIS mapping. A series of thematic maps were generated, showing the spatial distribution of flood resilience across the study area. These maps highlight areas of high flood risk and those with greater resilience, serving as a valuable tool for urban planners, urban managers and policymakers.

Validation and Ground-Truthing: Ground-truthing was conducted to validate the GIS-based vulnerability map. A total of 15 sites were visited across the Lekki–Epe corridor, covering areas classified as high, moderate, and low vulnerability zones. Validation was based on observed flood evidence, drainage conditions, land use patterns, wetland status, and infrastructure exposure. GPS coordinates and field photographs were collected at each location. Where discrepancies existed between field observations and GIS outputs, satellite imagery was rechecked, local observations were consulted, and necessary adjustments were made to improve the accuracy of the final vulnerability map.

To generate the weights for the socio-environmental criteria using the Ordinary Weighted Average (OWA) approach in flood resilience assessment for the study, values were assigned based on the relative importance of each criterion and supported by relevant literature presented in Table 2.

The OWA weighting scheme was derived using an expert-informed ranking approach supported by established GIS-based multi-criteria decision analysis (MCDA) practices in coastal vulnerability studies [23].

Weights were assigned based on the relative importance of each criterion in coastal hazard susceptibility, particularly within the Lekki–Epe coastal environment and subsequently normalised to ensure comparability across layers. To reduce subjectivity, the weighting structure was cross-checked against published coastal vulnerability applications and subjected to basic sensitivity testing, which confirmed that the spatial vulnerability pattern remained stable under alternative weight permutations. This aligns with best practices in OWA-based environmental modelling, where robustness is assessed through scenario variation [23].

Table 2 *Rank and weight of socio-environmental criteria for flood resilience*

Criterion	Description	Rank	Weight
Elevation	Low-lying areas are more prone to flooding.	0.2	1-5
Rainfall Intensity	High rainfall areas are more susceptible.	0.2	1-5
NDVI (Vegetation Density)	Dense vegetation buffers flood impact.	0.15	1-5
Proximity to waterbody	Areas close to water bodies face greater risks due to overflow and inundation	0.15	5-1
Proximity to Wetland	Wetlands act as natural flood buffers, reducing the risk	0.15	5-1
NDWI (Water Body Proximity)	Areas close to water bodies face greater risks due to overflow and inundation.	0.15	5-1
	TOTAL	1	

The variation in ranking direction (5–1 versus 1–5) reflects the functional role of each criterion. Exposure-related variables (e.g., proximity to waterbody) were ranked 5-1 to represent decreasing vulnerability, while resilience or protective variables (e.g., vegetation cover) were reversed (1-5) to reflect their mitigating effect. This ensures directional consistency, such that higher aggregated OWA outputs correspond to higher vulnerability.

3. Results and Discussion

3.1 Elevation Profile of the Study Area

The elevation of the Lekki-Epe Corridor ranges from 0 to about 61 meters above sea level (Figure 2). The highland areas in the corridor are in the inland areas especially in the northern Epe and Ikorodu, covering about 12% of the study area. These areas are less likely to be inundated and provide natural flood resilience. In contrast, lower elevations predominate in coastal communities such as Maroko, Makoko, Ibeju, Ilagbo, Ise, Iwopin, Ibese, Agboyi, Obada amongst others. According to previous studies, coastal cities located below 10 meters above sea level are more vulnerable to tidal flooding and permanent inundation due to climate change and sea level rise [4], [9], [24].

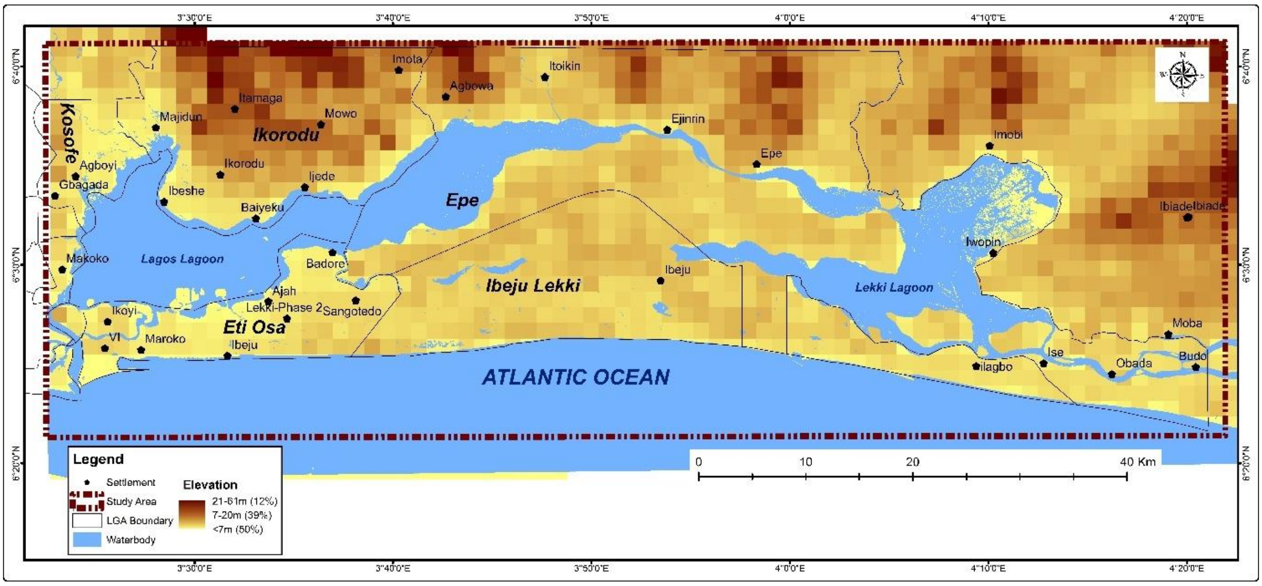

Fig. 2 *Elevation profile for Lekki-Epe corridor*

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Coastal flooding, storm surges, and sea-level rise pose significant threats to low-lying areas near the Atlantic Ocean, such as the Lagos and Lekki Lagoons [25], particularly during periods of high tides and heavy rainfall. Rapid urbanization is also increasing impervious surfaces and raising the risk of flooding in the Lekki-Epe corridor.

3.2 Rainfall Dynamics

As illustrated in Figure 3, the Lekki-Epe corridor experiences rainfall that ranges from 1,631 - 1,967 mm per year. The eastern part of the region experiences the most precipitation, especially in the vicinity of Epe and Ibeju-Lekki LGA, which impacts communities like Ilagbo, Iwopin, Imobi, Moba, and Ise. Rainfall is relatively lower in the western coastal regions, such as Eti-Osa and Ibeju-Lekki. In Lagos State, frontal influences and convective activity result in inland areas receiving somewhat more rainfall, which is consistent with this spatial pattern and broader climatic trends [12], [13]. According to Otusanya et al. [13], rainfall in the study area is also bimodal, with peaks usually occurring in June and September, which correspond to the major and minor rainy seasons in southwestern Nigeria. The high-intensity rainfall during these periods, combined with impervious urban surfaces, leads to stormwater accumulation, poor infiltration, and waterlogging in more urbanized areas such as Lekki and Victoria Island [26]. The interaction between elevated rainfall and low terrain significantly influences coastal erosion and infrastructure degradation in flood-prone zones.

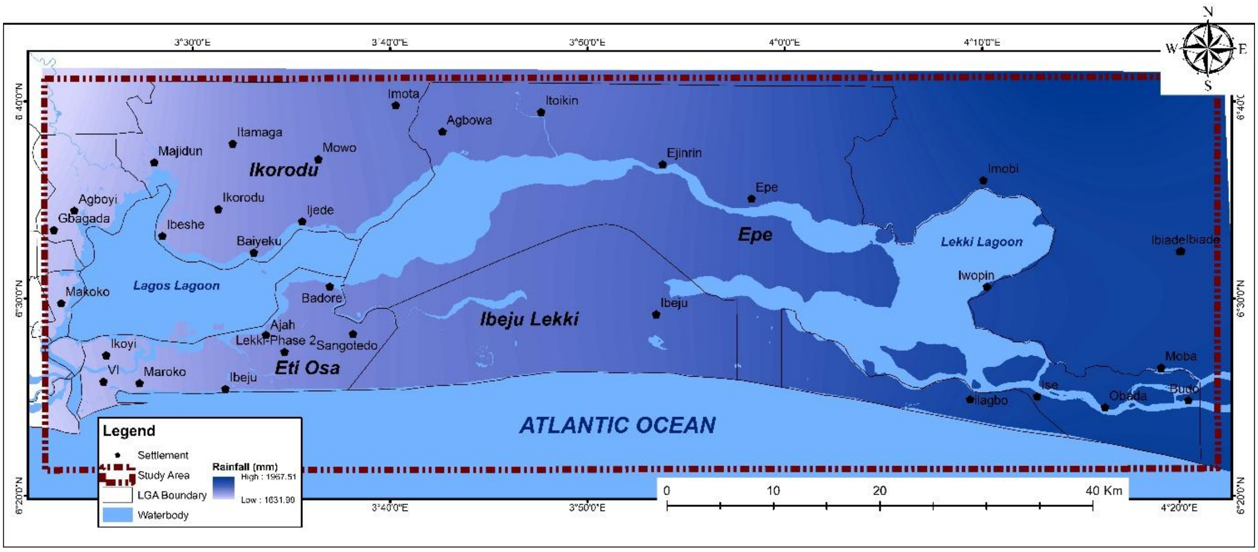

Fig. 3 *Rainfall dynamics for Lekki-Epe corridor*

3.3 Vegetation Health Profile

The Normalized Difference Vegetation Index (NDVI) is a widely used remote sensing metric for assessing vegetation health and density. NDVI values range from -1 to +1 as expressed by [1], [27] represent low to high vegetation health and density respectively. The vegetative health of the study area ranges from High and moderate to Low vegetation zones (Figure 4). The high vegetation zones (0.32-0.54), cover about 24% of the study area, and is characterized by dense vegetation, indicating a high plant cover. These areas are predominantly found in Ikorodu, Epe, and parts of Ibeju Lekki, where agricultural land, forests, and wetlands are more intact, suggesting good soil moisture availability and minimal urbanization impacts in these areas. The moderately vegetated areas (0.21-0.31), cover about 25% of the Lekki-Epe Corridor and represents areas with degraded vegetation, mixed land use, and transitional zones found in Eti-Osa and the southern parts of Ibeju-Lekki LGA, where urban expansion and infrastructure development have led to vegetation fragmentation. The low and non-vegetated areas (0.035-0.2 & -0.19-0.034 respectively) are largely less vegetated, dominated by waterbodies, bare land, and urban settlements. These areas cover about 14% and 37% respectively and dominate the corridor, prominent in Lagos and Lekki Lagoon, the Atlantic coastal stretch and highly urbanized areas in Lekki, Eti-Osa, and Victoria Island, among others.

The vegetation profile of the study area reflects the impact of urban sprawl, deforestation, and land reclamation for real estate and infrastructure, which are prevalent in the area. The loss of green cover exacerbates urban heat island effects, reduces carbon sequestration, and disrupts local biodiversity. The low vegetative areas along the coast and around the Lagos and Lekki lagoons are already known to be highly susceptible to flooding and erosion due to poor vegetation cover and exposure to rising sea levels [28].

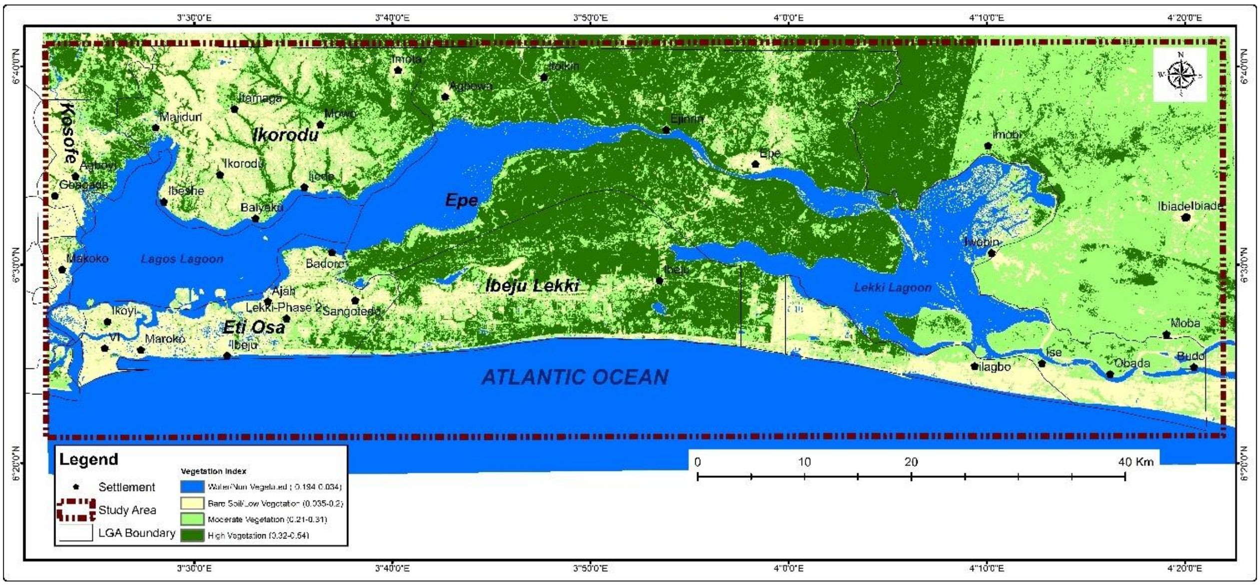

Fig. 4 *Vegetation profile for Lekki-Epe corridor*

3.4 Surface Moisture Profile

Normalised Difference Water Index (NDWI) is a remote sensing index used to detect water bodies and assess surface moisture. The NDWI profile of the area is presented as areas with High water presence (-0.03 to 0.24), moderate water presence (-0.22 to -0.03) and areas with low water presence (-0.22 to -0.50). Water bodies, such as the Lagos Lagoon, Lekki Lagoon, and the Atlantic Ocean, exhibit the highest NDWI values and cover over 37% of the study area, confirming their extensive water presence in the area (Figure 5). Rivers and smaller streams channeling into these major water bodies also show high reflectance, signifying continuous water flow. The coastal regions along the Atlantic Ocean and wetlands in Epe and Ibeju-Lekki are also characterized by high NDWI values, indicating substantial water retention.

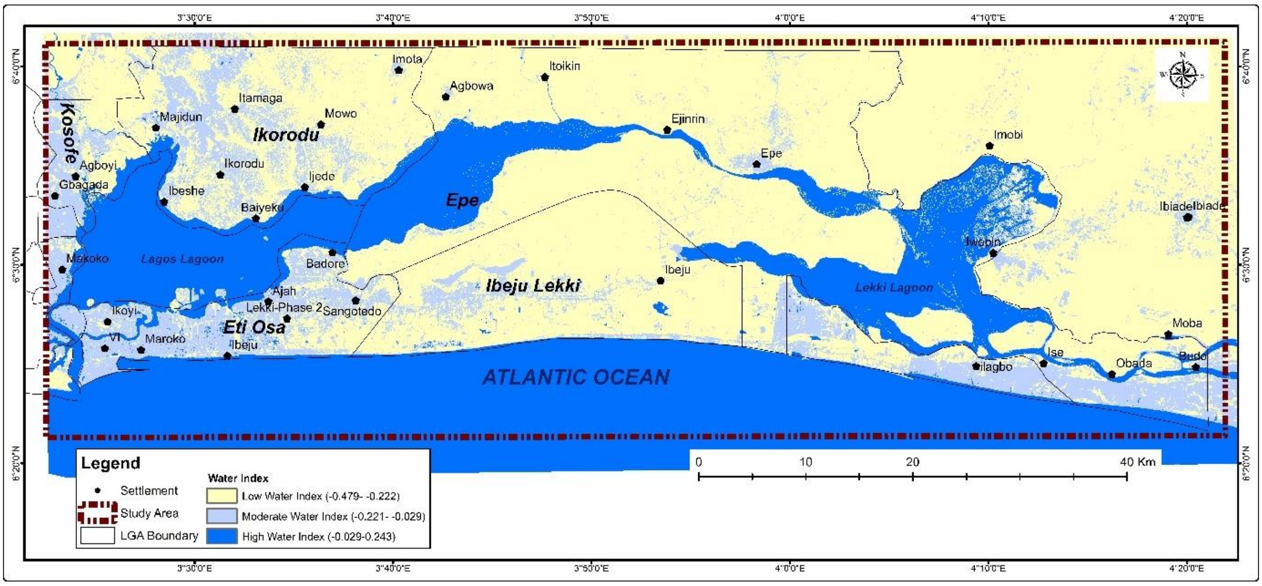

Fig. 5 *Surface moisture profile for Lekki-Epe corridor*

The moderate NDWI areas covers about 13% of the area and are found in wetland areas and marshy zones, mainly along riverbanks and floodplains in Epe and Ibeju-Lekki. These areas may be seasonally flooded, experiencing fluctuations in moisture levels due to rainfall and tidal influences. The low NDWI regions represent

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urbanised, built-up, and vegetated areas covers about 27% of the area and, indicates the presence of low or no surface water [1], [29]. Eti-Osa, Lekki, and parts of Ibeju-Lekki exhibit negative NDWI values, which correlate with urban expansion, land reclamation, and deforestation, especially the negative NDWI zones in Eti-Osa and Lekki indicate areas where urban development has replaced natural water bodies [30]. Land reclamation projects in the Lekki Free Trade Zone and Eko Atlantic City could further alter the hydrological balance, affecting flood control mechanisms [31].

3.5 Proximity to Waterbodies

Proximity to waterbodies has been shown to have a significant impact on disaster risk assessment, urban development, and environmental sustainability, as it affects flood susceptibility, biodiversity preservation, land-use planning, and groundwater recharge [32], [33]. The Lekki-Epe corridor, with its extensive coastal and lagoon systems, has varying degrees of proximity to waterbodies. Figure 6 illustrates the study's proximity to waterbodies by segmenting the area into three zones: those closest to waterbodies or high proximate communities (less than 7,000 meters), those with intermediate proximity (7000–15,000 meters), and those with low proximity (above 15,000 meters).

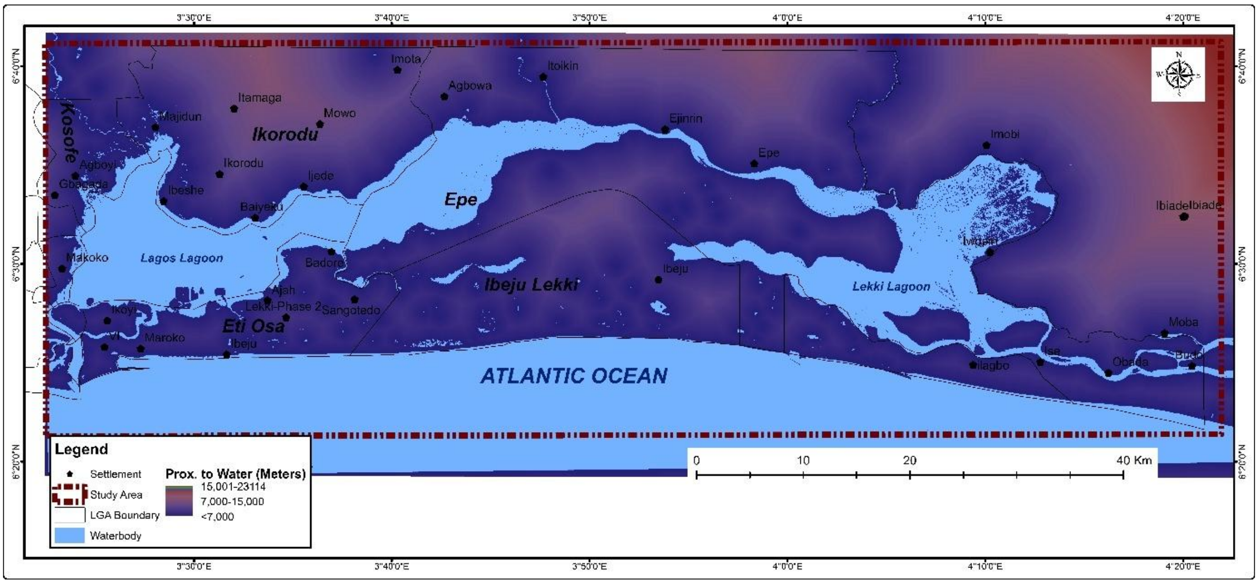

Fig. 6 *Proximity to Major waterbodies in Lekki-Epe corridor*

The high proximity areas are the major water bodies in the study area and proximate communities, such as Epe, Iwopin, Maroko, Ilagbo, Ise, Obada, Ijede, Baiyeku, Ibeshe, and Ibeju, among others. These areas experience frequent water influence, making them crucial for fishing, transportation, and tourism. However, it has been shown that high flood risks exist due to sea-level rise and storm surges, especially in Eti-Osa and coastal Lekki [34].

The moderate proximity zones are found in Ikorodu, Kosofe, and interior Epe, where wetlands and streams influence local water availability and soil moisture. These zones are ideal for agriculture and groundwater recharge, making them significant for food production and ecosystem services [35]. Urban expansion in Ibeju-Lekki is increasing impervious surfaces, reducing natural drainage and heightening flash flood risks [36]. The low proximity zones are in the northern parts of Ikorodu and Epe, the farthest from major water sources, having lower flood risks but face water scarcity issues, necessitating a reliance on groundwater and artificial reservoirs. Deforestation and land-use changes in these areas have been assessed to impact regional hydrology, affecting water recharge rates [37].

3.6 Proximity to Wetland

According to Ye et al. [38], wetlands are essential ecosystems that regulate flooding, purify water, preserve biodiversity, and sequester carbon. Wetlands, such as mangroves, lagoons, and estuaries, are crucial to the Lekki-Epe corridor's capacity to support both natural and human activities. The region's agricultural practices, urban growth, and disaster resilience are all impacted by the area's proximity to wetlands. Different Local Government Areas (LGAs) have varying distances from wetlands, as indicated by the proximity map (Figure 7), which displays a gradient from light brown (low proximity) to dark brown (high proximity).

Eti-Osa, Ibeju-Lekki, and Epe are the areas closest to wetlands (Low Proximity, 2700 m), where the Atlantic coastal wetlands, Lagos Lagoon, and Lekki Lagoon predominate. Wetlands in these areas support fishing, aquaculture, and other water-based livelihoods [39]. However, they are highly vulnerable to flooding and sea-level rise, necessitating the implementation of conservation strategies and adaptive land use planning. Moderate Proximity Zones (2,700 - 5,425 m) are in northern Ibeju-Lekki and parts of Ikorodu, where wetlands gradually transition into urban and semi-urban areas. These regions benefit from wetland-influenced soil fertility, making them suitable and fertile for agriculture and forestry. However, rapid urbanisation and wetland encroachment pose risks to ecosystem services and biodiversity [40]. The High Proximity Zones (>5426 m) are in northern Kosofe and Ikorodu, which are the farthest from major wetlands.

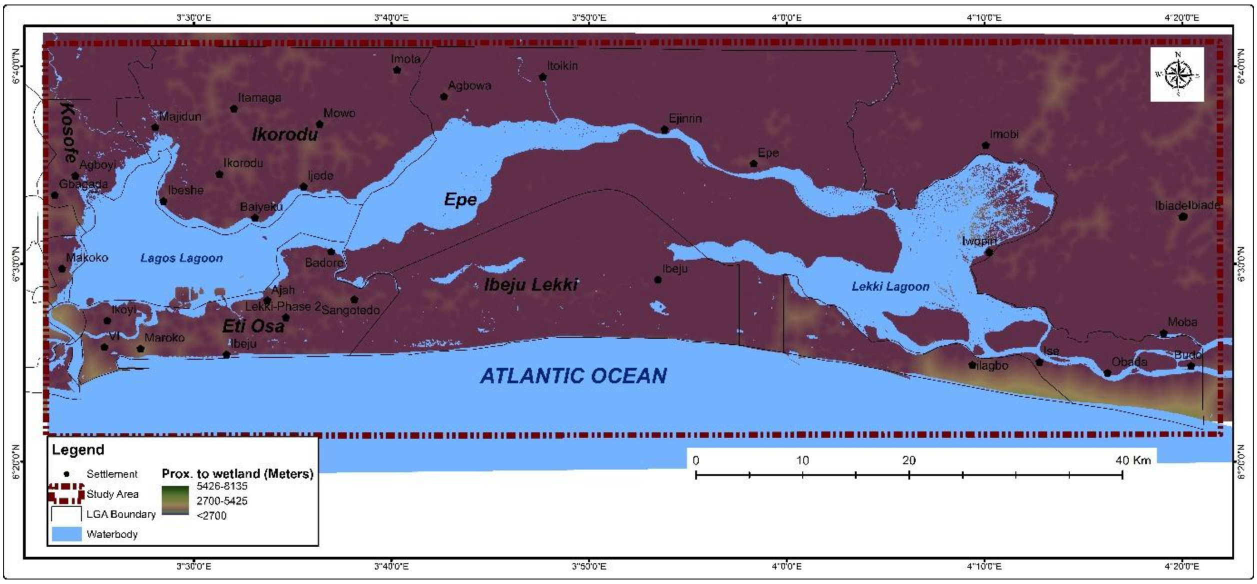

Fig. 7 *Proximity to wetland for Lekki-Epe corridor*

3.7 Vulnerability Risk Assessment

Vulnerability mapping is a critical tool for assessing areas at risk of environmental hazards, flooding, and land-use conflicts [41]. The Lekki-Epe corridor, a rapidly growing region in Lagos State, is vulnerable to environmental degradation due to urban expansion, climate change, and wetland encroachment. The map (Figure 8) classifies the area into different vulnerability levels ranging from Very Vulnerable (red) to Very Low Vulnerability (green), which have significant implications for population safety, infrastructure resilience, economic activities, and environmental sustainability. Figure 8 presents the vulnerability risk assessment for the Lekki-Epe Corridor and shows that 69% of the corridor fall within the Very Vulnerable zones followed by 17% for Vulnerable zone, 11% for Moderately Vulnerable among others.

Specifically, Ibeju-Lekki, Epe, Eti-Osa, Kosofe, as well as proximate areas to the major waterbodies in Ikorodu and Epe LGAs are all included in the very vulnerable zones. These regions are particularly vulnerable to climate-related hazards, including erosion and flooding. Their location in low-lying coastal wetlands and floodplains, which increases the likelihood of natural disasters and infrastructure damage, is the primary cause of their vulnerability. Northern Ikorodu and a few isolated areas in Epe are moderately vulnerable. These areas are subject to seasonal flooding and land degradation, making them moderately vulnerable to environmental hazards. These regions may become high-risk areas if appropriate action is not taken [42]. On the other hand, the northeastern region of the study area is home to most of the Very Low Vulnerability zones for human habitation and other activities as it offers stable land for development and are less vulnerable to flooding.

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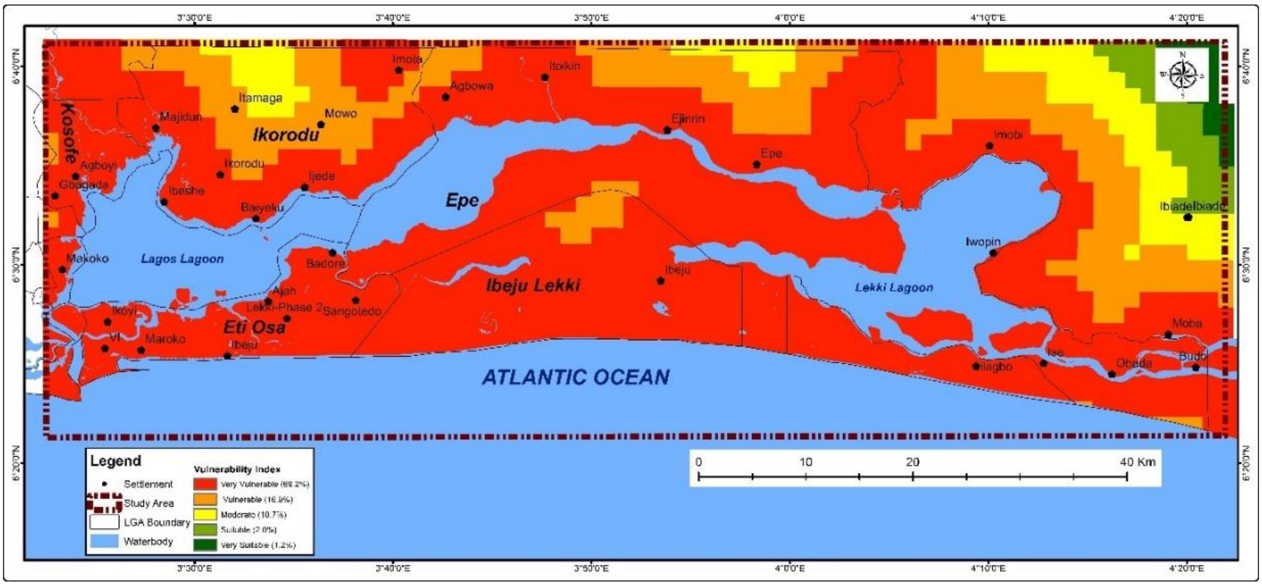

Fig. 8 *Vulnerability risk assessment for Lekki-Epe corridor*

4. Implications of Findings

There are profound socioeconomic and environmental implications associated with the high vulnerability status of the Lekki-Epe corridor. Regarding the impact on the population, heavily populated coastal areas such as Eti-Osa and Ibeju-Lekki are vulnerable to displacement due to frequent flooding. There is enormous pressure on land, housing, and social services in these areas due to the growing rural-to-urban migration, which exacerbates poverty and fosters the development of informal settlements [43]. Moreover, stagnant floodwaters and inadequate sanitation facilities are likely to contribute to the spread of waterborne illnesses, such as cholera and malaria [44].

There is also a significant economic impact of vulnerability as important infrastructure, such as water distribution facilities, power supply systems, and road networks, are susceptible to frequent flood damage. The high cost of maintenance and repairs deters investment and interferes with economic activity. A significant business hub, the Lekki Free Trade Zone, is particularly vulnerable to environmental risks that may discourage further investment. The local economy also depends heavily on the tourism and real estate sectors, both of which are negatively impacted by periodic flooding, which lowers property values and degrades the soil.

In terms of ecology, the loss of wetlands in the red zones lowers the area's natural flood-buffering potential by destroying habitat and biodiversity. Furthermore, by increasing carbon emissions and exacerbating urban heat island effects, the rapid deforestation and land reclamation for urban projects make people more vulnerable to the impacts of climate change. Water bodies are further deteriorated by pollution from industrial processes and urban runoff, endangering fisheries and residents' means of subsistence [45].

5. Conclusion

This study highlighted the spatial distribution of environmental risk susceptibility and offered a thorough vulnerability assessment of the Lekki-Epe corridor. According to the findings, a sizable section of the region is classified as highly vulnerable, especially in areas that are rapidly becoming more urbanized, encroaching on wetlands, and lacking in infrastructure resilience. Flooding brought on by climate change, population expansion, and unregulated land-use changes all make these vulnerabilities worse.

This vulnerability has ramifications that go beyond immediate environmental issues, including threats to livelihoods, economic disruptions, and the loss of vital infrastructure. Communities can be displaced, local economies may suffer greatly, and public resources dedicated to disaster response and mitigation may be overwhelmed by frequent flooding and environmental degradation. Furthermore, unrestrained physical developments and inadequate environmental governance continue to jeopardise the region's ecological integrity, especially its wetlands and biodiversity.

A multifaceted strategy that incorporates community involvement, sustainable urban planning, and science-based decision-making is needed to address these issues. Stricter land-use regulations, better infrastructure, and the implementation of nature-based solutions like wetland restoration and green infrastructure are all necessary to increase the region's resilience. Furthermore, early warning systems and disaster preparedness can be enhanced by utilising cutting-edge technologies like real-time flood monitoring and machine learning-driven predictive analytics.

To further improve vulnerability assessments, future studies should concentrate on integrating real-time data collection, socioeconomic vulnerability indices, and dynamic climate modelling. It is feasible to develop flexible and sustainable solutions that reduce risks and improve resilience in the Lekki-Epe corridor by encouraging cooperation between local communities, environmental scientists, urban planners, and legislators.

Finally, this study underscores the urgent need for proactive coastal management interventions in response to the high level of vulnerability identified across the study area which indicates that more than four-fifths of the landscape is already under moderate to extreme risk, confirming a critical spatial concentration of vulnerability along the coastal zone. Without immediate and coordinated intervention, this pattern is likely to intensify, increasing the likelihood of erosion, flooding, habitat loss, and socio-economic disruption.

The findings provide a quantitative basis for action, supporting the need for variable buffer zones and differentiated land-use controls based on vulnerability classes and proximity to water bodies. Such measures would enhance resilience by prioritizing protection and relocation strategies in the most at-risk zones while guiding sustainable development in relatively stable areas.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Odunuga, S.S., Badru,G.S., Otusanya, O.O.;* ***data collection:*** *Otusanya, O.O., Sadiku, O.A.;* ***analysis and interpretation of results:*** *Otusanya,O.O., Badru, G.S., Sadiku, O.A.;* ***draft manuscript preparation:*** *Otusanya, O.O., Badru, G.S., Sadiku, O.A., Odunuga, S.S. All authors reviewed the results and approved the final version of the manuscript.*

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